

**Demonstration Program for Reducing Nitrate Leaching through Improvements
to Irrigation Efficiency and Fertilizer/Cover Crop Management**

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Executive Summary

Introduction and Objectives

This project began with discussions in 1989 and 1990 among Kurt Schulbach, Blaine Hanson, and Stuart Pettygrove (Univ. of Calif.) and Matt Zidar (Monterey Co. Water Resources Agency). Jacques Franco (CDFA), Ron Edwards (SCS), Sig Christierson (grower), and Louise Jackson (U.C.) along with several others played a significant role in preliminary discussions.

By the late 1980s, several state and local organizations had "chewed" on the water quality problems -- especially nitrate in agricultural areas -- observed in Monterey Co. and other coastal areas. Significant reports were produced by the Monterey Co. Water Resources Agency, later by the ad hoc nitrate committee. A large amount of technical data had accumulated from U.C. field research in the 1970s and 1980s showing the role of irrigated vegetable cropland in nitrate emissions and particularly the importance of water and nutrient management factors. Two other points were clear: In spite of a mass of circumstantial evidence, there was no clear, direct proof for fertilization of vegetable crops being the main culprit. Also, it took several years -- perhaps decades to create the problem, so it was unlikely that the groundwater could quickly be cleansed of nitrate.

Given all these factors, it was felt that Cooperative Extension should work together with others in identifying, developing, and promoting the use of Best Management Practices that would be agronomically and economically acceptable to farmers.

The long-term objective of this project and all follow-up activities is to have vegetable producers in the Salinas Valley adopt more practices in their crop, water, and nutrient management that will reduce the quantity of nitrate percolating below the root zone. It was recognized that many BMPs are already in widespread use, e.g., split applications of fertilizer N. We felt that therefore we would devote effort in this project to relatively untested technologies that could change the setting in which nutrients and water are managed. We decided to focus on documenting drip irrigation performance on coarse-textured soils, and to the possible role of cover cropping in reducing winter leaching. We also were aware that a large amount of field research has already been conducted on N and water management of cool-season vegetable crops in California and elsewhere.

The specific objectives of the project were:

1. Compare crop and irrigation system performance under surface drip, subsurface drip, and furrow irrigations systems in coarse-textured soil over a period of several crops. While there has been much research on many aspects of these systems, few studies have compared them in a field-length experiment. Small plot comparisons over a short time period (single crop) are nearly worthless if the goal is to compare irrigation system performance.

2. Evaluate the practical methods available to extension workers and others to estimate or measure nitrate leaching losses and the effect of improved management on such losses. It was recognized that success in reducing leaching loss could not be accurately deduced simply by measuring crop and irrigation system performance. On the other hand, standard methods for quantifying nitrate leaching loss below the root zone were too expensive to be used in the many field experiments and demonstrations that will be needed to address the nitrate problem.
3. Demonstrate the use of nitrate trapping cover crops in grower fields. This practice had already been found to be effective in research plots conducted by Louise Jackson in studies over a two-year period.
4. Produce two publications: (i) A technical literature review of nitrogen and water use by cool-season vegetable crops for use by a variety of professionals who are involved in developing general recommendations -- agronomists, fertilizer company technical representatives, extension workers, SCS, etc.; (ii) A shorter brochure with BMPs for N and water management for the same crops that could be distributed to the industry -- growers, PCAs, laboratory, and others responsible for making or carrying out recommendations.

Summary of Accomplishments

The results of this project are shown in the attached five appendices. A summary of accomplishments and findings follows:

Technical literature review: A 94-page technical literature review covering 240 references was completed by Lee Stivers under the supervision of Louise Jackson. Many of the documents reviewed have had limited distribution or are unpublished altogether. The review includes baseline data for lettuce, celery, cauliflower, and broccoli on crop N uptake, fertilizer requirement, rate of N uptake, tissue N concentrations, water use, and the recommendations made by others for N and water management. The review concludes that several areas -- rate of N accumulation, N - yield relations, dry tissue critical N levels -- have been studied extensively. Topics with scant literature include soil and plant tissue quick tests, fresh sap quick tests, methods for maximizing use of N from mineralized soil organic matter, use of soil-crop models to estimate effects of irrigation and fertilization on leaching, and a detailed understanding of N budgets and fates under the management and environmental setting along the coast. The literature is complete but currently is being edited into a more condensed, "user-friendly" format. This activity is being supported by CDFA FREP funds and should be completed within the next few months. Three sets of the reviewed documents are currently available in

Cooperative Extension offices in Salinas (Louise Jackson's laboratory at the USDA ARS station and at the Monterey Co. Cooperative Extension office on Wilgart Way) and at U.C. Davis (Stuart Pettygrove's office, Department of Land, Air and Water Resources). An additional set has been given to the Monterey Co. Water Resources Agency.

Best Management Practices Brochure: The text has been completed, but it has not yet been edited and printed in a brochure format. This can be easily done when the specific distribution plan has been agreed upon. The BMPs are categorized according to the system used in the University of Arizona's 1991 bulletin, *Nitrogen Fertilizer Management in Arizona* by Doerge, et al. Five general BMPs are listed with more specific GPs (guidance practices) under each BMP.

Use of Nitrate-trapping Cover Crops: Winter cover crops were demonstrated at three sites in the northern Salinas Valley during the 1991-92 winter. One of the sites was drip-irrigated. At two of the sites, cover crops were successful in reducing the level of nitrate at the time of incorporation and earlier. No problems were encountered with incorporating or preparing the seed bed for the following vegetable crop. Planting of cover crops on prepared beds and then reuse of these beds for the following vegetable crop was successful and can be considered as a form of minimum tillage. This work was also supported by a lettuce board grant to Louise Jackson. CDFA FREP funds are being used to further edit the report.

Furrow-drip irrigation system comparison on sandy loam soil: This experiment covers 4.8 acres at Major Farms near Soledad. Before the drip irrigation was installed in 1991, an unfertilized crop of oat hay was grown to decrease the antecedent nitrogen content of the soil. The area was divided into three plots, 24 beds wide each x the length of the field (860 ft). Three plots were set up for furrow irrigation, surface drip, and subsurface drip in the summer of 1991. Two lettuce crops were grown -- harvested in October 1991 and May 1992. A third crop was grown in the late summer 1992, but data analysis is not complete. The rest of the field outside these three plots is in drip. The grower carried out all cultural practices in a conventional manner. The project team managed N and water on the drip system. Each plot was divided into four six-bed fertilizer N rate plots. Closely spaced N rates were used.

During the first crop, none of the systems performed well due to design and operation problems. It was difficult to measure furrow irrigation performance due to fluctuations in the advance of water down the furrow. The drip system had problems stemming from partial collapse of flexible submains. These problems were solved between the first and second lettuce crop. A major improvement was the installation of a surge valve on the furrow irrigated plot. This allowed a water savings of one or more inches on each irrigation in 1992 compared to what would have occurred without the technique.

It does not appear that surface drip is practical due to frequent damage to the tape that occurred during cultivation and the cost of removing and replacing tape with each crop.

The estimated cost of drip amortized over a three-yr tape life and not including tape removal costs or any increase in management was \$162/acre. In the fall 1991 crop, the furrow system produced 783 cartons/ac with 10.1 inches of water applied. The drip systems produced somewhat lower yields due to problems with the collapsed submain: 678 carton/ac on 4.4 inches with the surface drip, and 744 cartons/ac on 4.7 inches on the buried drip. Crop residues that were unharvested contained 40 to 50 lb N/acre.

In the spring 1992 crop, about two more inches of water was applied with the furrow system than in the drip, showing the advantage of the surge valve. Unfortunately, due to miscommunication, a mid-season furrow irrigation was applied too late, resulting in failure of heads to size up, and thus no yield was taken by the grower.

During the spring crop, soil water content following irrigations was monitored. Water content distribution was somewhat more variable along the length of the field in the furrow plot than in the drip plots, especially late in the season, in spite of the use of surge irrigation. Also, more detailed soil texture measurements revealed that while most of the soil falls into the sandy loam textural class, there are large variations in sand, silt, and clay that may contribute to variations in leaching and soil water holding capacity.

Variability in plant growth and nitrogen content was measured. No obvious correlation was observed with soil water content and texture variations, however further examination of the data are required. It is clear that any monitoring of soil or tissue will have to be conducted with some attention to the variability across the field. It may be desirable to sample in areas with the greatest leaching potential as determined by soil texture and irrigation water distribution pattern.

Methods for Estimating Nitrate Leaching

Appendix E of this report reports the use of soil sampling to estimate leaching losses at the Major Farms site over the 1991-92 winter (approx. 9.9 inches rainfall); also presented is a brief review of alternative approaches either involving direct measurement or modeling. We estimated winter leaching losses of 90 lb N/acre in some areas of the field, with an average of about 50 lb N/acre, with no large difference between drip and furrow irrigation systems. These estimates involve several assumptions and are probably minimum values. Much higher fall nitrate levels were found to six feet in the furrow plot than in the drip plot, but it is not clear how much this was due to higher sand content in that plot or a difference in soil organic matter. It cost at least \$5000 to obtain these estimates, imperfect as they are. With one additional sampling, much better estimates could have been made; also it is likely that an adequate estimate could have been made with fewer than the 48 to 96 cores collected in the 4.8-acre area.

Two approaches to a less expensive estimate of nitrate leaching are suggested: (1) Use of the EPIC model of soil-plant-nitrogen behavior. This has been used on lettuce data and can produce economic return outputs in a form usable by growers. For the model to be sensitive to the various management alternatives being considered, accurate baseline information must

be used, including the solute transport characteristics of the soil. Some very promising techniques are under development by soil scientists for estimating the mean and range of soil hydraulic properties at a much lower cost, but we still do not have an "off-the-shelf" procedure for doing this.

(2) Use of anion exchange resin traps for direct measurement of quantity of nitrate leached over time looks promising in spite of the problem that installation of the traps disturbs the soil through which nitrate bearing solution will percolate. This is the only direct measurement method not involving the use of N-15 labelled fertilizer that is not hampered by high soil nitrate levels at the beginning of the measurement period.

Recommendations

What can be done to reduce the contamination of groundwater in the Salinas Valley by nitrate that comes from agricultural fields? Several reviews by state and local groups have reached similar conclusions as to the physical strategies that should be pursued. These are summarized by Peter Canessa in his Task 3 205(j) project report to the Monterey Co. Water Resources Agency. The principal goal must be to "minimize deep percolation while maximizing on-farm irrigation efficiency consistent with independent, profitable farming practices" (Canessa, January 1992). Canessa points out that reducing deep percolation may not have a large impact on water conservation because currently nearly all return flows reenter the aquifer and are available for reuse. Rather, the main benefit of minimizing deep percolation (if done in combination with use of fertilizer nitrogen BMPs) would be the improvement of groundwater quality.

We agree with this as far as it goes. Clearly, more efficient use of N fertilizer must be coordinated with a reduction in percolation of water below the crop root zone. However, it should be remembered that the nitrogen cycle is complex and that nitrogen leached from cropland in most instances is not simply unused fertilizer being transported past the roots by the irrigation that follows fertilizer application. The strategy proposed by Canessa and others before him does not address the significant contribution of nitrate from winter leaching in fallow fields. In our field study in a sandy loam soil used for lettuce production (Appendix E), even though conservative fertilization practices were followed, movement of nitrate below a depth of two feet averaged at least 50 lb N/acre and in some areas of the field was as high as 90 lb N/acre during a 16-week fallow period with about 11 inches of rain plus irrigation. Field research in Monterey and San Benito Counties conducted by Louise Jackson (UC Davis Dept. of Vegetable Crops) and colleagues has shown the very high potential for mineralization of crop residues and soil organic matter during the fall and winter in this area and resulting high levels of nitrate. Improvements in irrigation water and fertilizer N management, while definitely needed, will not directly effect winter leaching from fallow fields.

We make two general recommendations. These are followed by a list of more specific high-priority needs.

Our first overall recommendation is to continue a program of research and development and technology transfer that addresses both the cropping period and the fallow period. Continued strong – perhaps strengthened – input from the users of technical information is required both in the identification of appropriate applied research activities and in development of the details of practices to be recommended for adoption by growers and others. We believe that technology transfer and applied research activities cannot and should not be separated. Also frequent interaction between the grower/fertilizer/irrigation community and the research/education groups will produce far more effective results than unilateral activities.

Our second overall recommendation is that research and development activities be targeted to the regions and soil types in the Salinas Valley that are most likely the source of the problem. One effort to identify these regions and soils is in the "Section 208" report by Ririe, et al. (1982?). We have attached pages 271-274 of the report to this Executive Summary. The authors have identified the areas with the following characteristics: (i) highly fertilized, shallow-rooted crops are grown (ii) coarse-textured soils are present (iii) the area is not underlain by restricting layers that provide some protection to groundwater; or there is other evidence that groundwater contamination is a problem.

Following is a list of needed research and technology transfer activities. Where University of California activities are being conducted or proposed, we so note. In some instances personnel and financial resources are not currently available to carry out these activities.

Our recommendations are based on the assumption that groundwater nitrate content will eventually be reduced if cool-season vegetable producers adopt best management practices in their use of water, fertilizer nitrogen, and organic amendments, and in the way they manage fallow periods. We do not attempt here to review all the alternatives and institutional constraints to solving the nitrate problem. We restrict our recommendations to identification of the knowledge gaps that deserve immediate attention and the technology transfer activities that would be effective and are consistent with the research and public service missions of the University of California.

Research Needs

1. For drip irrigated vegetables, daily N uptake rates are needed. Such numbers provide growers and fertilizer dealers with an easily-comprehended value that can be related to rate of injection of N into the drip system. Daily N uptake rates are used by Cooperative Extension in Florida in its N management recommendations for drip irrigated crops. Also, the University of Arizona has published daily uptake N curves.
2. Development of interpretive guidelines for pre-plant and pre-sidedress nitrate soil tests are

needed for crops grown under all irrigation systems. Research has shown that extremely high soil nitrate levels early in the season are relatively common due to the ability of Salinas Valley soils to generate nitrate during fallow periods. No early-season N fertilization is required in such situations, but some research is needed to bracket the dividing line between nitrate levels that permit reduced fertilization with no risk to the crop and lower concentrations of nitrate where some risk is present.

3. Further work is needed on the use of soil solution access tubes (i.e., vacuum samplers or tension lysimeters) and their use in combination with plant tissue analysis for identifying high-nitrate situations in drip-irrigated crops. Some research is being conducted on this topic under a FREP grant.
4. Diagnostic criteria for fresh sap N content need to be determined for coastal California cool-season vegetable crops. Many growers will use plant tissue analysis only if results can be obtained quickly in or near the field. This precludes procedures that require drying of plant tissue. Some work is being conducted on this subject now. Also being investigated is the Minolta chlorophyll meter, another in-field monitoring device.
5. Field research is needed to obtain an understanding of the impact of immediate past crop residues (vs older soil organic matter) and tillage on the nitrogen dynamics of the soil between cropping periods. This will help in assessing the impact of various cover cropping cultural practices, tillage, and vegetable crop residue management. Many opportunities exist to manipulate fallow-period soil nitrate levels by reduction of tillage, use of permanent beds, removal of crop residue, addition of low-N soil amendments, and cover cropping. Research in this area should be expanded.
6. Development of site characterization methods suitable for use in crop-soil-nitrogen models is urgently needed. Models, such as EPIC, appear to have much promise for assessing the relative impact of various practices on nitrate leaching at a much lower cost than field experimentation. Also, new approaches to obtaining the needed field data inputs are being developed by soil physicists. These include the use of less expensive measuring devices (e.g. time domain reflectometry), and the development of statistical relations among soil properties that are easily estimated (bulk density, soil water content) and properties that are very expensive to measure (hydraulic conductivity).

Technology Transfer Activities

1. Further development of educational materials (handbooks, brochures, newsletters, videos) must be done with far more user input than in the past. This could be accomplished by

establishment of a work group in which user group participants (growers, fertilizer company personnel, laboratory operators, professional agronomists, etc.) are paid a consulting fee. This will help with the problem of having the extension/SCS/research participants being paid a salary while they "pick the brains" of individuals who are volunteering their time. We are currently submitting a proposal to the State Water Resources Control Board to provide funding for a writer/technical expert and the travel and consulting fees required to establish such a work group. The output of this activity will be a manual with much more detail and feasibility considerations than appears in the typical BMP list (for example Appendix D of this report).

2. On-farm demonstration of surge irrigation and collection of installation and operating costs specific to the Salinas Valley. This should be targeted to coarse-textured soils. Many experts and farmers already agree that this is an effective technique in some situations, permitting lighter irrigations in furrows without sacrifice of uniformity. An additional need is the training of farm irrigation personnel.
3. On-farm demonstration of the integrated soil solution/plant tissue monitoring system being developed by Richard Smith for drip-irrigated fields. More research is needed (see above research list), but enough success has been achieved that the practice should be expanded to other farms while diagnostic criteria are being developed. The method requires a high level of interest by the grower in monitoring, but it also could be conducted by an employee, consultant, etc. A key feature is that the soil solution and plant tissue nitrate levels can be determined by quick-test technology at a savings in time and laboratory expense. One goal of the demonstration would be to show that the reduced accuracy of quick test methods (compared to a laboratory analysis) is still adequate for helping the grower make fertilization decisions. Richard Smith and Kurt Schulbach will continue working in this area supported by our FREP grant in 1993. Also Tim Hartz (UC Davis Department of Vegetable Crops) is conducting research on this topic and will be producing a video on drip N management techniques for vegetable crops -- also supported by a FREP grant.
4. Continued on-farm demonstration of the use of nitrate-trapping cover crops is needed. This needs to be done with attention to the timing of planting, incorporation, bed management, and the possible need for irrigation. Less resources should be devoted to documenting the impact at each site on nitrate movement, however see above research need #5.
5. Finally, more attention should be given to establishing the number of people using BMP practices now, so that progress can be documented. It is critical that this not be a general survey of growers in the entire valley -- whoever "walks in the door". Such surveys should be conducted in coordination with the identification and detailed description of specific practices. A small survey targeted to users in the high-priority areas and soils (see

above) and for use of specific practices would produce benchmark data that could be compared to a follow-up survey in five years. For example, the survey should probably determine the number of acres under surge irrigation within regions with coarse-textured soils where the potential is high for leaching of nitrate. Peter Canessa, in his Task 3 report, also emphasizes the need for baseline data, such as the number of growers and acres under drip irrigation. We do not currently have plans for conducting such a survey; possibly the workgroup described above in item 1 could develop the level of detail that would be useful and that practically could be obtained.

Best Management Practices for Nitrogen and Water Use in Cool Season Vegetable Production

A Best Management Practice is one that is agronomically and economically feasible and that minimizes harm to soil, water, air, and the health of humans and other animals. BMPs can range in scope from general strategies to field-specific recommendations. The following is a list of cultural practices that in some cases will reduce nitrate leaching from cool season vegetable cropland. This list includes common-sense practices, many of which are already in widespread use. It also includes a few practices that have been demonstrated to reduce nitrate leaching in some settings, but for which economic feasibility is not known. These do not meet the definition of BMP but can be considered "candidate" practices. This list is not intended to be complete. It emphasizes reduction of non-point source pollutants. Also not all these practices are appropriate for every farm.

The list is organized into five general BMPs which are subdivided into more specific "Guidance Practices" (GP). This follows the terminology used in *Nitrogen Fertilizer Management in Arizona* (Doerge, Roth, and Gardner, 1991, University of Arizona).

BMP 1. Percolation of irrigation water below the crop root zone shall be limited to that needed for salinity control. In most of coastal California, winter rainfall plus unavoidable inefficiencies in irrigation will remove salts from the root zone. Low rainfall, use of saline irrigation water, or application of high rates of cattle manure will result in an increased leaching requirement. Uniform limitation of subrootzone percolation will conserve nitrogen in the root zone and make it easier to manage fertilizer.

GP 1.1. Conduct irrigation system performance evaluation to determine sources of non-uniformity. In some areas, Department of Water Resources Mobile Laboratory personnel can conduct this evaluation. A performance evaluation will help determine whether sprinkler or drip systems are designed properly, or whether components are all functioning properly. Furrow irrigation evaluation is useful for determining the distribution of water over a field and can show where improvement is possible.

GP 1.2. Operate sprinklers in times of low wind. This is a common practice in many locations.

GP 1.3. Use alternate sets in hand-move sprinkler irrigations. This is a common practice. By placing lines in between previous locations, unavoidable non-uniformity in one set will partially offset that in the previous set.

GP 1.4. Use frequent, light irrigations. Cool season vegetables have shallow root systems (see accompanying table). Especially, in coarse-textured soils, percolation

below the root zone is unavoidable with conventional furrow irrigation.

GP 1.5. Install drip irrigation. This is not yet a proven practice in economic terms in coastal vegetable crop production, but both research and grower experience show tremendous promise for ability to precisely control amount, timing, and uniformity of water and nutrients supplied to the crop.

GP 1.6. Shorten furrow lengths to promote uniformity. The potential for this may not be great since in many vegetable farms, run lengths are already as short as is economically practical. In fields with runs longer than 1000 ft or that have coarse-textured soils with high intake rates, this should be considered.

GP 1.7. Where furrows are blocked, begin furrow flows at the highest feasible flow rate, then cut back. Sometimes irrigators use a slower flow rate initially and increase the flow rate as the day progresses. This substantially decreases uniformity and can result in heavy leaching at the upper end of the field.

GP 1.8. Use surge irrigation on furrow systems. Surge irrigation requires installation of a valve that will switch water back and forth between two sets of furrows. This results in bigger heads of water; also, water flows over soil previously wetted thereby reaching the end of the field faster. Surge irrigation permits much lighter irrigations at a given level of uniformity. It has been demonstrated to improve performance on coarse-textured soils. Comparisons of surge and conventional furrow irrigation along the coast have shown that surge irrigation may need 30% less water to cover the field. It currently is not in widespread use among coastal vegetable growers.

GP 1.8. Use soil water monitoring devices or check soil moisture directly before irrigating. Many growers already check soil moisture content. Amount of water applied is often a matter of irrigating as lightly as possible while covering the entire field. Tensiometers are not in widespread use but are worth consideration. In some instances, pre-irrigations are excessive where rainfall has already filled the profile. In such cases, soil water content should be considered in determining the amount of water to apply.

BMP 2. The rate of fertilizer nitrogen applied shall be the minimum required for crop yield and quality. Typical crop N uptake amounts and harvest removals are shown in the accompanying table.

GP 2.1. In setting N fertilizer rates, take into account soil nitrate levels at preplant or pre-sidedressing decision points. Field studies at several locations in the Salinas Valley have shown very high residual pre-plant nitrate levels. There is no point in sidedressing or pre-plant fertilizing when nitrate levels are extremely high. Soil nitrate can be measured in soil samples or in soil solution collected by or vacuum extractors (like an empty tensiometer). Samples from different soil types or from unrepresentative areas at the upper and lower ends of fields should not be composited. Researchers still need to set diagnostic guidelines before this practice can be enthusiastically endorsed. Samples should be refrigerated or air-dried quickly and analyzed by a competent laboratory. Soil solution can be analyzed with quick-test methods such as a portable specific-ion meter or nitrate test strips where proper precautions are taken and less accuracy is needed.

GP 2.2. Measure nitrate content of irrigation water and reduce fertilizer N rate accordingly. To calculate lb N/acre-inch, multiply nitrate-N content by 0.22. For example: If well water has 15 ppm nitrate-N, a three-inch furrow irrigation will result in application of 9.9 lb N/acre. Nitrate content of water can be measured by a laboratory or estimated with nitrate test strips or a portable specific-ion electrode if less accuracy is needed.

GP 2.3. Use on-farm trials—for example, by use of fertilizer applicator skips and doubles—to monitor performance of crop. The information gained in such trials will be useful in making future crop fertilization decisions and can also assist in setting rates for mid- and late-season N fertilization in the current crop.

BMP 3. Fertilizer N applications shall be timed to match the crop need.

GP 3.1. Supply fertilizer N to crops in multiple, low-rate applications, rather than a smaller number of large applications. This is practiced by most vegetable growers. Research on cool-season vegetable crops shows the need for a very small total amount of N (<10 lb N/acre) through thinning. This N must be positionally available to the small root system. Larger quantities of N (2-4 lb N/acre daily, possibly higher) are not needed until the peak growing period (see table). For lettuce, this period of peak uptake will last only a few weeks.

GP 3.2. Monitor soil and plant tissue nitrate levels. This can provide information on whether to fertilize but will be less useful for deciding how much N to apply. Just before the first sidedressing, test soil for nitrate and reduce or eliminate sidedressing when very high levels of nitrate are present. In early- to mid-season in drip irrigation,

monitor soil or soil solution weekly. Do not fertilize when nitrate levels are high. Add Apply fertilizer N when levels begin to drop. A few growers with drip systems are monitoring soil solution nitrate levels. This will not be widespread until more experience is obtained in interpreting soil or soil solution nitrate concentrations. Petiole or midrib sampling is also very useful in drip-irrigated systems. A new practice being tested by U.C. researchers is analysis of the fresh sap from plant petioles or leaves. Quick test techniques are available.

GP 3.2. Avoid fall preplant applications of N for late winter or spring plantings. Instead use starter fertilizer positioned close to seed. Fall preplant applications of N at time of bed listing has been a common practice in some areas and often results in very low recovery of N by the crop due to leaching or denitrification losses. It is a less common practice now.

GP 3.3. Do not apply fertilizer N to crops when mean weekly temperature is less than 55° F. Research has shown that lettuce uptake of N slows dramatically when temperatures drop below this point. Nitrate present in the root zone will then be subject to leaching.

GP 3.4. Do not apply the nitrate form of fertilizer when rain is expected. The ammonium form of N is favored because it is not leachable. When the soil is cool, several weeks will be required for a significant amount of conversion to nitrate.

GP 3.5. Avoid heavy fall applications of livestock manure. Mineralization occurs rapidly in the mild fall and winter on the coast. Use of conservative rates of low-N organic matter, such as in compost or weathered manure, is a better practice. A total nutrient analysis (NPK or just N) and determination of water content is recommended.

GP 3.6. Use slow release fertilizers. Slow release fertilizers have been agronomically effective on some crops in field and greenhouse studies. Several different types are available. Disadvantages are high cost per unit nutrient and -- because release rates are dependent on both fertilizer characteristics and some environmental conditions -- difficulty in predicting availability to crop. The release rate of each type is influenced by different environmental variables. Some research has shown agronomic effectiveness and reduced nitrate leaching. Slow release fertilizers may have a role where for some reason multiple fertilizer sidedressings will not be possible. Slow release fertilizer use is common in strawberry production but not in vegetable production.

BMP 4. Fertilizer N shall be applied in a position that results in maximum crop uptake efficiency.

GP 4.1. Fertilizer N should be banded near plant roots rather than broadcast. Broadcast followed by incorporation results in poor recovery by cool season vegetables. Banding of fertilizer is a very common cultural practice.

GP 4.2. Starter fertilizer should be banded over the seed at very light rates or below and to one side of seeds or small plants.

BMP 5. Crop rotations and crop residues shall be managed so that low soil nitrate levels will be present during the rainy season. Research in the Salinas Valley has shown the importance of winter leaching of nitrate derived from decomposition of crop residues and soil organic matter. Due to mild temperatures, frequent tillage associated with multiple cropping, and the incorporation of high-N crop residues, row cropped soils in coastal California produce large quantities of nitrate year round.

GP 5.1. Grow non-legume cover crops during fallow periods. In other cropping systems, such as organic vegetable production, it may be desirable to add nitrogen to the system with leguminous green manure crops like vetch. In conventional systems, the purpose of cover cropping is to trap nitrate in the root zone and reduce winter leaching. Merced rye, oats, or barley are the traditional cover crop species. In recent field studies in the Salinas Valley, less well-known species like phacelia (*Phacelia tanacetifolia*) have also been effective in trapping nitrate and do not produce as great a volume of troublesome residue. Cover cropping on permanent beds has also been demonstrated. Reduction in tillage in this system may also lessen the amount of nitrate in the soil.

GP 5.2. For soil physical and biological improvement, use amendments with a high C:N ration (e.g., certain composts), especially when these are applied in the fall or winter. Low-N composts with rice hulls or wood shavings, spent mushroom compost, well-aged gin trash/cattle manure compost, etc. will increase biological immobilization of N and improve soil quality. Use of low-N materials does not reduce the danger of salinity build-up or damage to the crop stand.

GP 5.3. When time available between cool season vegetable crops is long enough, grow a deep-rooted crop such as a winter cereal or forage, sugarbeets, or tomatoes, rather than leave the land in bare fallow. Such crops have been traditionally grown along the coast but acreage has declined for both economic and agronomic reasons. Unless market conditions favor these crops, they will not displace the cool-season vegetables. But they should be considered as alternatives to the shorter-season non-cash cover crops or when for any reason, the higher value shallow-rooted crops cannot be grown.

Table 1. N uptake and rooting characteristics of cool-season vegetables.

	Harvest N Removal lb N/acre	Above-ground N Content at Harvest, lb/acre	Peak N Uptake Rate lb N/acre-day	Max. Rooting Depth, inches	Water Extraction Depth, inches
Lettuce	50-120	100-125	2-4	24-30	18
Celery	50-125	150-280	2-4	12+	12
Broccoli	90 (5 ton crop)** 60-110	250-300** 140-250	as high as 8?*	36?	24
Cauliflower	125 (10 ton crop)** 110	250** 235	3-4 as high as 7?*	36?	24

**from Doerge, et al. 1991. Nitrogen Fertilizer Management in Arizona, University of Arizona.
(Except for **, all values abstracted from Stivers and Jackson, 1992, Literature Review: Nitrogen and Water Use
by Lettuce, Celery, Broccoli, and Cauliflower) Report in preparation to Monterey County Water Resources
Agency, State Water Resources control Board, and Calif. Dept. of Food and Agriculture)